Associations of Levels of Total Nitrogen, Potassium, and Sodium in Petioles and in Thin Juice with Weight of Roots Per Plot, Percentage Sucrose and Percentage Apparent Purity in Sugar Beets[1, 4]

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Studies conducted (see Payne et al.)[5] to determine levels of total nitrogen, potassium, and sodium in the petioles as compared with levels of these same chemicals in the thin juice, at time of harvest, have shown that there are interactions of genotypes and material analysed. It was found that some genotypes, as compared to others, tended to have higher levels of the three chemicals in the petioles as compared with the thin juice of the sugar beet (*Beta vulgaris L.*). For other comparisons the reverse was found to be true. The purpose of the study reported in this article is to determine relations between weight of roots per plot, percentage sucrose, and percentage apparent purity and levels of total nitrogen, potassium and sodium in the petioles as compared with levels of these same chemicals in the thin juice. Also the relations between levels of phosphorus in the petioles with weight of roots per plot, percentage sucrose and percentage apparent purity were studied. The petioles analysed were collected at time of harvest and the thin juice was prepared from the roots harvested.

Literature Review

The studies on the associations of levels of total nitrogen, potassium, and sodium in the petioles and in the thin juice with weight of roots per plot, percentage sucrose, and percentage apparent purity provide information fundamental to an under-

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5 Numbers in parentheses refer to literature cited.

standing of combining ability, especially for yield of sugar per plot. The literature pertaining to combining ability in sugar beets is rather limited. This probably is due to the fact that until quite recently the number of inbred lines of sugar beets available for testing has been and, comparatively speaking, still is rather limited.

Oldemeyer (5) used a commercial sugar beet variety and the German red beet as topcross testers to determine the general combining ability of inbred lines of sugar beets and concluded that the German red beet is satisfactory to test general combining ability for both yield and percentage sucrose. Peterson and Dickenson (9) using the red-marker beet to test for general combining ability found that the single crosses producing the most sugar per acre were those whose parents were high in general combining ability when tested by crossing with the red-marker beet and whose F_1 hybrids exhibited heterosis for percentage sucrose.

Oldemeyer and Rush (4) made a very interesting study using male-sterile testers. Seventeen self-fertile inbred lines and one open-pollinated variety of sugar beets were crossed to five cytoplasmic male-sterile tester lines. The hybrids and their corresponding parents were grown in a field test. The results of this test showed that there are differences among the inbred lines for general combining ability and that specific combining ability is important, particularly in regard to yield. Heterosis and phenotypic dominance were found for both yield and sucrose percentage. Parental performance showed little association with the combining ability of their respective inbreds. This points out the necessity of making test crosses when evaluating inbreds. The variance attributable to the males and females is considered by them to be an index of that part of the over-all variation among the test crosses due to the general combining ability of the parents. The interaction variance (male$\times$female) is considered an index of that part of the over-all variation due to specific combining ability. To study the effect of specific combining ability, the means of the individual crosses were adjusted by adding to, or subtracting from them, the deviations of the means of all respective crosses of each parent from the test averages.

Helmerick et al. (3) employing varietal crosses made rather extensive studies pertaining to heterosis and combining ability. They concluded that rather substantial gains could be made by utilizing heterosis in the production of beet sugar. They also studied the environmental and genetic variances and identifiable proportion of genetic deviates and pointed out the value of this information in breeding hybrid populations of sugar beets.

Powers et al. (10) conducted studies which showed that certain planting arrangements in isolation plots containing two parental sources resulted in approximately 68 percent of the progeny being the result of cross-fertilization between sources and that probably the remaining 32 percent of the progeny resulted from cross-fertilization between plants within sources. Other studies (11, 12, 13) showed that certain inbreds produced hybrids that exhibited heterosis for percentage sucrose and percentage apparent purity. It is expected that heterosis for weight per root would be obtained. Such was found to be the case.

Chemical genetic studies (Powers et al., 13) revealed that the dominance phenomena for the chemical characters associated with percentag sucrose and percentage apparent purity are such as to result in both of these characters exhibiting heterosis in hybrids between certain selected inbred lines. This indicates that by employing methods of breeding designed to utilize heterosis, hybrid populations that are superior in weight per root, percentage sucrose, and percentage apparent purity to those varieties now being grown for the production of beet sugar can be bred. Some such hybrid combinations involving inbred lines were obtained.

For methods of chemical analysis see Payne et al. (6, 7,) and for a review of the literature involving the heritability of the chemical characters see Powers et al. (11, 12) and Finkner et al. (2).

Materials and Design of the Experiment

The materials used in the study are as follows: There is a total of 20 populations in the experiment. One is a commercial variety, 4 are three-way hybrids, each composed of 3 inbreds, and 15 are F_1 hybrids each composed of 2 inbreds. The dates of harvest are September 14, October 3, and October 16. The experiment was conducted in 1961. The characters studied are weight of roots per plot, percentage sucrose, percentage apparent purity, and levels of total nitrogen, potassium and sodium in the petioles and in the thin juice, and levels of phosphorus in the petioles. Weight of roots per plot is expressed as kilograms, sucrose and purity as percentages, the levels of the chemical characters are expressed as milligrams per 100 grams in the petioles, and the levels of the chemical characters are expressed as milligrams per 100 milliliters of thin juice equated to a refractive dry substance of 10 in the thin juice. The thin juice was prepared by The Great Western Sugar Company by an oxalate method standard with them [see (1)]. In this process the nitrate nitrogen is removed. Hence the total nitrogen for the thin juice does not include all the nitrogenous compounds found in the total nitrogen analysis of the petioles. However, as shown by Powers et al. (12), the association between total nitrogen in the thin juice and the press juice is extremely high, most of the variability of one being accounted for by the variability of the other.

The design of the experiment is a split plot with populations randomized within replications and dates of harvest randomized within blocks. Each block is composed of three dates of harvest and each date of harvest has two replications with 20 populations randomized within each replication. There are five such blocks. Hence, the design of the experiment is a modified randomized complete block.

Results

The F values calculated from the analyses of variance for all the characters are listed in Table 1. For all characters, there are significant differences between means of populations. There are significant differences between means of dates of harvest for percentage sucrose and possibly for levels of sodium in the thin juice. The interactions having possible statistical significance are for the characters percentage sucrose, percentage apparent purity, and levels of sodium in the petioles. The interaction involving the levels of phosphorus in the petioles is fairly well established statistically. The data will be considered on the basis of the average of all dates of harvest as the amount of the variability accounted for by the interactions involving dates of harvest is small, comparatively. The interactions of greatest importance in this article involve populations, chemical constituents, and materials analysed.

The means for weight per plot, percentage sucrose, and percentage apparent purity; for levels of total nitrogen potassium, sodium in the petioles and in the thin juice; and levels of phosphorus in the petioles are listed in Table 2. Also, the least significant differences and the grand averages are listed at the bottom of this table. Powers et al. (13) have shown that very little of the environmental variability is included in the differences between the means of populations. Hence, the differences noted between means of populations are predominantly genetic. In this article, the data in Table 2 have their greatest interest in the degrees of association between the level of a chemical in the petioles and the level of the same chemical in the thin juice, their corresponding interactions, and the association of the level of these chemicals with the important agronomic characters, weight of roots per plot, percentage sucrose, and percentage apparent purity. The associations are determined by studying the simple correlation coefficients.

Table 1.—The F values calculated from the analyses of variance for weight per plot, percentage sucrose, percentage apparent purity, levels of total nitrogen, potassium, and sodium in the petioles and in the thin juice and levels of phosphorus in the petioles.[1]

Variation due to:	Weight per plot	Percentage sucrose	Percentage apparent purity	Total nitrogen		Potassium		Sodium		Phosphorus	Value of F at:	
				Petioles	Thin juice	Petioles	Thin juice	Petioles	Thin juice	Petioles	5%	1%
Populations[2]	33.59	22.81	22.38	6.85	41.84	48.87	19.43	9.62	9.36	8.37	1.60	1.92
Dates[3]	———	16.24	———	———	———	———	1.59	1.99	7.80	1.80	4.46	8.65
P X D[2]	———	1.41	1.42	1.22	1.20	1.33	———	1.45	1.08	1.90	1.42	1.64

[1] ——— signifies that the error mean square is the larger.

[2] An error mean square composed of the interactions BXP, RXP, BXRXP, BXPXD, RXPXD, and BXRXPXD with 513 degrees of freedom was used to calculate F values for populations and populations X dates.

[3] An error mean square composed of the interaction BXD with 8 degrees of freedom was used to calculate the F value for dates.

Table 2.—Means for weight per plot, percentage sucrose, and percentage apparent purity for levels of total nitrogen, potassium, and sodium in the petioles and in the thin juice and levels of phosphorus in the petioles.

Population	Entry number	Weight per plot	Sucrose	Purity	Total nitrogen Petioles	Total nitrogen Thin juice	Potassium Petioles	Potassium Thin juice	Sodium Petioles	Sodium Thin juice	Phosphorus Petioles
		Kg	%	%	Mg/ 100gm	Mg/ 100ml	Mg/ 100gm	Mg/ 100ml	Mg/ 100gm	Mg/ 100ml	Mg/ 100gm
52-430 X 52-407 F_1	1	6.595	14.9	93.9	1365.0	49.2	16.2	66.3	40.6	50.3	178.0
52-305 CMS X (52-430 X 52-407) F_1	2	5.678	14.9	92.6	1376.7	56.1	24.2	69.9	32.3	43.9	186.7
52-305 CMS X 52-430 F_1	3	4.560	15.8	93.7	1374.0	49.6	26.5	65.7	28.5	37.2	194.2
52-305 CMS X 52-407 F_1	4	5.542	14.7	91.0	1345.0	62.1	17.0	73.4	34.5	39.3	166.0
52-430 X 52-307 F_1	5	7.047	15.2	95.0	1470.8	40.9	18.0	53.9	35.9	45.2	201.6
52 305 CMS X 52-307 F_1	6	5.975	14.6	93.6	1489.8	52.3	27.8	62.2	32.2	41.8	196.2
52-430 X 52-408 F_1	7	7.358	15.5	94.7	1431.8	44.8	21.1	60.4	36.9	36.8	186.8
52-430 X 54-520 F_1	8	5.498	15.7	92.9	1488.7	57.6	13.8	60.0	35.3	36.5	195.1
52-305 CMS X 54-520 F_1	9	5.643	15.3	92.1	1383.5	65.6	17.9	65.2	31.3	37.8	176.8
52-430 X 54-565 F_1	10	4.802	16.3	95.6	1330.8	41.6	18.4	44.7	32.9	30.9	221.0
52-305 CMS X 54-565 F_1	11	5.050	16.1	94.9	1431.7	45.6	24.1	48.2	30.9	30.6	202.8
52-305 CMS X 54-458 F_1	12	5.257	14.8	91.8	1321.0	64.9	16.4	71.9	32.0	39.4	170.1
52-430 X 54-346 F_1	13	5.465	16.2	95.7	1278.2	37.4	14.2	41.9	32.3	38.0	195.2
52-305 CMS X 54-346 F_1	14	5.052	15.6	94.9	1315.3	42.0	20.7	53.1	32.7	35.9	182.3
52-305 CMS X (52-430 X 54-346) F_1	15	5.173	15.8	94.2	1316.2	44.5	20.5	53.6	30.4	37.3	182.3
52-305 CMS X (52-430 X 54-520) F_1	16	5.095	15.4	92.2	1442.6	65.2	22.4	67.2	30.8	36.3	194.2
52-305 CMS X 34 F_1	17	6.128	15.2	92.9	1485.7	61.3	24.7	57.9	35.4	42.1	172.1
52-305 CMS X (54-458 X 34) F_1	18	6.173	15.1	92.0	1404.5	60.1	21.0	62.1	33.7	36.8	177.9
54-565 X 52-407 F_1	19	5.625	14.8	92.5	1488.2	57.4	17.9	73.2	39.0	46.0	204.7
A56-3	20	7.843	14.0	93.1	1531.2	54.4	16.4	60.7	35.9	55.7	206.5
LSD at 5%		0.414	0.34	0.80	77.8	3.9	1.6	5.7	2.7	5.5	13.5
LSD at 1%		0.545	0.45	1.06	102.6	5.1	2.1	7.6	3.5	7.2	17.8
Average		5.778	15.3	93.5	1403.5	52.6	20.0	60.6	33.7	39.9	189.5

Associations

The simple correlation coefficients are listed in Table 3.

Weight per plot is positively associated with levels of total nitrogen and sodium in the petioles and with levels of sodium in the thin juice. The association of weight per plot with levels of potassium in the petioles is not statistically significant, only 4 percent of the variability being accounted for by covariation. The association between percentage sucrose and total nitrogen in the petioles is negative and 22 percent of the variation is covariation. Likewise, the association between percentage sucrose and level of sodium in th petioles is negative and here 18 percent of the variation is covariation. In no case is the association between percentage apparent purity and levels of total nitrogen, potassium, and sodium in the petioles statistically significant.

Table 3.—Correlation coefficients for weight of roots per plot, percentage sucrose, and percentage apparent purity with levels of total nitrogen, potassium, sodium and phosphorus.[1]

Character and material Analyzed	Weight per plot	Percentage sucrose	Percentage apparent purity
Total Nitrogen			
Petioles	0.54	—0.47	—0.21
Thin juice	—0.03	—0.54	—0.95
Potassium			
Petioles	—0.20	0.03	0.02
Thin juice	0.09	—0.70	—0.85
Sodium			
Petioles	0.66	—0.43	—0.03
Thin juice	0.70	—0.80	—0.07
Phosphorus			
Petioles	—0.00	0.28	0.56

[1] The approximate value of r at the 5% level is 0.273.

Weight per plot does not show any statistically significant association with levels of total nitrogen or potassium in the thin juice. However, levels of total nitrogen in the thin juice and percentage apparent purity are very closely associated and the association is negative. Also levels of potassium in the thin juice are rather closely associated with percentage apparent purity and again the association is negative. With this high a degree of association, it is not at all likely that the breeder can obtain genotypes having a high purity and a high level of total nitrogen in the thin juice. The same associations hold for percentage sucrose and levels of total nitrogen and potassium in the thin juice but the asociations are not nearly so pronounced. Likewise, percentage sucrose is rather strongly associated with levels of sodium in the thin juice and the association is negative, 64 percent of the variability being covariation.

These results show that at time of harvest it is much more desirable to have the higher levels of total nitrogen, potassium, and sodium in the petioles rather than in the thin juice; as here they are positively associated with weight of roots per plot and are not closely associated negatively with either percentage sucrose or percentage apparent purity. Levels of phosphorus in the petioles show little, or no, association with weight per plot, but the associations with percentage sucrose and percentage apparent purity are statistically significant and positive. However, the closeness of the association is not marked, the greatest amount of the variability being covariation is 31 percent.

The interactions of weight per plot, percentage sucrose, and percentage apparent purity with total nitrogen in the petioles and in the thin juice are depicted by the mean listed in Table 4. These population are selected from Table 2 because they show that certain combinations of characters can be obtained. The comparisons between the means of the F_1 hybrid 52-305 CMS X 54-458 and the F_1 hybrid 52-430 × 52-408 show that an increase of total nitrogen in the petioles and a decrease of total nitrogen in the thin juice are accompanied by increases in weight of roots per plot, percentage sucrose, and percentage apparent purity. The comparisons of F_1 hybrid 52-430 × 52-408 with A56-3 show that further increases of total nitrogen in the petioles and in the thin juice are accompanied by a further increase in weight per plot and by decided decreases in percentage sucrose and in percent apparent purity.

Table 4.—Interactions of weight per plot, percentage sucrose, and percentage apparent purity with levels of total nitrogen in the petioles and in the thin juice.

Population	Weight	Sucrose	Purity	Total nitrogen	
				Petioles	Thin juice
	Kg	%	%	Mg/100gm	Mg/100ml
52-305 CMS × 54-458 F_1	5.257	14.8	91.8	1321.0	64.9
52-430 × 52-408 F_1	7.358	15.5	94.7	1431.8	44.8
A56-3	7.843	14.0	93.1	1531.2	54.4
LSD at 5%	0.414	0.34	0.80	77.8	3.9
LSD at 1%	0.545	0.45	1.06	102.6	5.1

These comparisons confirm the relations shown by the correlation coefficients; namely, that increases of total nitrogen in the petioles rather than in the thin juice can result in an increase in all 3 of the important agronomic characters, weight per plot, percentage sucrose, and percentage apparent purity. They further show that an increase of total nitrogen in the thin juice does not have an adverse relation with weight of roots per plot but it does have decidedly adverse relations with percentage sucrose and percentage apparent purity. Hence, weight of roots per plot, percentage sucrose, and percentage apparent purity in some populations are favorably associated with total nitrogen in the petioles but not with total nitrogen in the thin juice. Hence, the breeder should be able to increase these three desirable agronomic characters by breeding genotypes having high levels of total nitrogen in the petioles at time of harvest. These results indicate that higher levels of total nitrogen in the petioles are associated with higher yields and are not associated with lower percentage sucrose and lower percentage purity; whereas higher levels of total nitrogen in the thin juice are not associated with higher yields but are associated with lower percentage sucrose and lower percentage apparent purity. Then, it seems as though the plant breeder can improve both yield and quality by genetically controlling the location, at time of harvest, of the higher levels of total nitrogen; that is, breeding those genotypes having higher levels of this chemical in the petioles instead of the thin juice.

The means showing the interactions of weight per plot, percentage sucrose, and percentage apparent purity with levels of potassium in the petioles and in the thin juice are listed in Table 5. The comparisons involving the two F_1 hybrids 52-305 CMS × 54-458 and 52-430 × 52-408 show that an increase in levels of potassium in the petioles and a decrease in the levels of the potassium in the thin juice are accompanied by material increases in weight per plot, percentage sucrose, and percentage apparent purity. The comparisons between populations 52-430 × 52-408 and A56-3 show that a decrease in the level of potassium in the petioles and no change in the level of potassium in the thin juice are accompanied by decreases in percentage sucrose and percentag apparent purity and a comparatively small increase in weight per plot. As was the case for levels of total nitrogen, increased levels of potassium in the petioles are associated with increased

Table 5.—Interactions of weight per plot, percentage sucrose, and percentage apparent purity with levels of potassium in the petioles and in the thin juice.

Population	Weight	Sucrose	Purity	Potassium: Petioles	Potassium: Thin juice
	Kg	%	%	Mg/100gm	Mg/100ml
52-305 CMS × 54-458 F_1	5.257	14.8	91.8	16.4	71.9
52-430 × 52-408 F_1	7.358	15.5	94.7	21.1	60.4
A56-3	7.843	14.0	93.1	16.4	60.7
LSD at 5%	0.414	0.34	0.80	1.6	5.7
LSD at 1%	0.545	0.45	1.06	2.1	7.6

percentage sucrose and percentage apparent purity, whereas increases in levels of potassium in the thin juice show the reverse associations. Again, if higher levels of potassium are essential to those metabolic processes conducive to higher yields, it is more desirable to have these higher levels in the petioles at time of harvest rather than in the thin juice.

The means showing the interactions of weight per plot, percentage sucrose, and percentage apparent purity with levels of sodium in the petioles and in the thin juice are listed in Table 6. Comparing the F_1 hybrids 52-305 CMS × 54-458 and 52-430 × 52-408 it can be seen that an increase in levels of sodium in the petioles and no material change in levels of sodium in the thin juice are accompanied by increases in weight of roots per plot, percentage sucrose, and percentage apparent purity. Comparing 52-430 × 52-408 and A56-3 no material change in levels of sodium in the petioles and an increase in levels of sodium in the thin juice are associated with decided decreases in percentage sucrose and percentage apparent purity and a moderate increase in weight of roots per plot. Again, if higher levels of sodium are conducive to favorable metabolic processes in the sugar beet plant, it is preferable to have the higher levels in the petioles rather than having the higher levels in the thin juice at time of harvest.

Table 6.—Interactions of weight per plot, percentage sucrose, and percentage apparent purity with levels of sodium in the petioles and in the thin juice.

Population	Weight	Sucrose	Purity	Sodium Petioles	Sodium Thin juice
	Kg	%	%	Mg/100gm	Mg/100ml
52-305 CMS × 54-458 F_1	5.257	14.8	91.8	32.0	39.4
52-430 × 52-408 F_1	7.358	15.5	94.7	36.9	36.8
A56-3	7.843	14.0	93.1	35.9	55.7
LSD at 5%	0.414	0.34	0.80	2.7	5.5
LSD at 1%	0.545	0.45	1.06	3.5	7.2

Table 7.—Interactions of weight per plot, percentage sucrose, and percentage apparent purity with levels of phosphorus in the petioles.

Population	Weight	Sucrose	Purity	Phosphorus Petioles
	Kg	%	%	Mg/100gm
52-305 CMS × 54-458 F_1	5.257	14.8	91.8	170.1
52-430 × 52-408 F_1	7.358	15.5	94.7	186.8
A56-3	7.843	14.0	93.1	206.5
LSD at 5%	0.414	0.34	0.80	13.5
LSD at 1%	0.545	0.45	1.06	17.8

The means showing the interactions of weight per plot, percentage sucrose, and percentage apparent purity with levels of phosphorus in the petioles are listed in Table 7. For all three populations listed in this table, the higher levels of phosphorus in the petioles are associated with increases in weight of roots per plot and there are no consistent relations involving percentage sucrose and percentage apparent purity. However, from the correlation coefficients listed in Table 3 it can be seen that, on an average, the genetic variability shows the association between weight of roots per plot and levels of phosphorus in the petioles to be negligible; whereas, those involving sucrose and purity are not marked but are statistically significant and favorable, being positive.

Discussion and Summary

(A) The associations between levels of total nitrogen in the thin juice, percentage sucrose, and percentage apparent purity are negative and for percentage apparent purity is extremely close. In fact, the association is so close ($r = -0.95$) as to practically preclude the possibility of genetically combining high total nitrogen in the thin juice with high percentage apparent purity. However, the association between high levels of total nitrogen in the petioles and high percentage apparent purity is much lower, only 4 percent of the variability being attributable to covariance. Moreover, the higher levels of total nitrogen in the petioles are positively associated with higher yields of roots (weight of root per plot). This indicates that high levels of total nitrogen in the petioles are conducive to greater weight of roots per plot. Percentage sucrose is adversely asociated with higher levels of total nitrogen in the petioles but the adverse associations are not as marked as for higher levels of total nitrogen in the thin juice. In fact, only 22 percent of the variability is covariance, indicating that genetically higher levels of total nitrogen in the petioles can be combined with higher percentage sucrose. The data in Table 4 for the F_1 hybrid 52-430 $\times$ 52-408, as pointed out in the discussion under results, show that these two chemical characters can be favorably recombined.

(B) Essentially the same findings hold for levels of potassium, sodium, and phosphorus. That is, it is much more desirable to have the higher levels of these chemicals in the petioles as contrasted with the thin juice.

(C) Further, it seems that the higher levels of total nitrogen, potassium, and sodium in the petioles are conducive, if not essential, to the production of higher yields. The higher levels of phosphorus in the petioles are associated with higher percentage sucrose and higher percentage apparent purity. The relation is stronger for percentage apparent purity than for percentage sucrose.

(D) Finally, there seems to be no reason why the metabolic requirements for higher yields of roots, higher percentage sucrose, and higher percentage purity cannot be met by producing and growing genotypes which, at the time of harvest, tend to have the higher levels of total nitrogen, potassium, sodium, and phosphorus in the petioles rather than in the thin juice.

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